Rangeland Ecol Manage 63:248–252 | March 2010 | DOI: 10.2111/REM-D-09-00025.1

Research Note

Shrub Microsite Influences Post-Fire Perennial Grass Establishment

Chad S. Boyd and Kirk W. Davies

Authors are research scientists, US Department of Agriculture, Agricultural Research Service, Eastern Oregon Agricultural Research Center, 67826-A Hwy 205, Burns, OR 97720, USA.

Abstract

Woody plants can cause localized increases in resources (i.e., resource islands) that can persist after fire and create a heterogeneous environment for restoration. Others have found that subcanopies have increased soil organic matter, nitrogen, and carbon and elevated post-fire soil temperature. We tested the hypothesis that burned sagebrush subcanopies would have increased seedling establishment and performance of post-fire seeded perennial bunchgrasses compared to burned interspaces. We used a randomized complete block design with five study sites located in southeast Oregon. The area was burned in a wildfire (2007) and reseeded in the same year with a seed mix that included non-native and native perennial bunchgrasses. Seedling density, height, and reproductive status were measured in October 2008 in burned subcanopy and interspace microsites. Non-native perennial grasses had greater densities than native species ($P < 0.001$) and were six times more abundant in burned subcanopies compared to burned interspaces ($P < 0.001$). Density of natives in burned subcanopies was 24-fold higher than burned interspaces ($P = 0.043$). Seedlings were taller in burned subcanopies compared to burned interspaces ($P = 0.001$). Subcanopy microsites had more reproductive seedlings than interspace microsites ($P < 0.001$). Our results suggest that under the fire conditions examined in this study, pre-burn shrub cover may be important to post-fire restoration of perennial grasses. Determining the mechanisms responsible for increased seeding success in subcanopy microsites may suggest tactics that could be used to improve existing restoration technologies.

Resumen

Las plantas leñosas pueden crear un aumento localizado de recursos (es decir, islas de recursos) que pueden persistir luego de un fuego generando un ambiente de restauración heterogéneo. Otros autores han encontrado que las áreas debajo del canopeo poseen más materia orgánica, nitrógeno y carbono (es decir, islas de recursos) y elevada temperatura edáfica luego de un fuego. Pusimos a prueba la hipótesis de que las áreas quemadas debajo del canopeo de *Artemisia tridentata* tendrían mayor establecimiento y mejor performance de plántulas de pastos perennes sembrados después del fuego comparado con las áreas quemadas en los espacios entre arbustos. Utilizamos un diseño completamente aleatorizado en bloques con cinco sitios de estudio en el sudeste de Oregon. El área había sido quemada en un incendio (2007) y resembrada el mismo año con una mezcla de semillas compuesta por especies de pastos perennes nativos y exóticos. En octubre de 2008 se determinaron la densidad de plántulas, su altura y estado reproductivo en micrositios quemados bajo canopeos y en los espacios entre arbustos. Los pastos exóticos exhibieron mayores densidades que las especies nativas ($P < 0.001$) y exhibieron una abundancia seis veces mayor en áreas quemadas debajo de los canopeos comparado con áreas quemadas en los espacios entre arbustos ($P < 0.001$). La densidad de pastos nativos en áreas quemadas debajo de canopeos fue 24 veces mayor que en los espacios quemados entre arbustos ($P = 0.043$). La altura de plántulas en áreas quemadas bajo canopeos fue significativamente mayor a la de plántulas en espacios quemados entre arbustos ($P = 0.001$). Los micrositios debajo de canopeos tuvieron más plántulas en estado reproductivo que los micrositios entre arbustos ($P < 0.001$). Nuestros resultados sugieren que para las condiciones de fuego estudiadas, la cobertura de arbustos previa al fuego podría influir sobre la restauración de pastos perennes posterior al fuego. La determinación de mecanismos responsables por el mayor éxito de implantación en micrositios debajo de canopeos podría sugerir tácticas para mejorar las tecnologías de restauración existentes.

Key Words: heterogeneity, interspace, resource island, revegetation, sagebrush, wildfire

INTRODUCTION

Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis* Welsh) plant communities periodically burn (Wright and Bailey 1982; Mensing et al. 2006) and are at risk of conversion to exotic annual grasses after fire (Stewart and Hull 1949; Young and Allen 1997). Establishment of desired vegetation is often needed after wildfires to restore ecosystem function and prevent invasion by exotic species (Beyers 2004; Keeley 2004; Hunter et al. 2006; Davies 2008; James et al. 2008). However, efforts to establish desirable vegetation are frequently unsuccessful in semi-arid and arid plant communities (O'Connor 1996; Rafferty and Young 2002; Eiswerth et al. 2009).

The probability of establishing desirable vegetation may vary with the spatial arrangement of resources in shrub communities. Shrubs often create resource islands, areas of higher resource concentrations, beneath their canopies (i.e., subcano-

The Eastern Oregon Agricultural Research Center is jointly funded by the US Department of Agriculture–Agricultural Research Service and Oregon State Agricultural Experiment Station.

Correspondence: Chad S. Boyd, US Department of Agriculture, Agricultural Research Service, Eastern Oregon Agricultural Research Center, 67826-A Hwy 205, Burns, OR 97720, USA. Email: chad.boyd@oregonstate.edu

Manuscript received 20 March 2009; manuscript accepted 13 October 2009.

pies; Jackson and Caldwell 1993a, 1993b; Schlesinger et al. 1996). These resource islands have been documented in sagebrush communities (Charley and West 1977; Doescher et al. 1984; Davies et al. 2007). Davies et al. (2009) speculated that, after fire, the burned subcanopies would be a more conducive environment for seedling establishment than burned interspaces. However, they did not test this theory, and the influence of resource islands on post-fire establishment of vegetation remains largely unexplored.

Although spatial heterogeneity of resources is reduced with fire in Wyoming big sagebrush plant communities, burning does not completely eliminate the resource island effect (Davies et al. 2009). The objective of this study was to determine if the success of post-fire seeded perennial grasses differed between interspace and subcanopy microsites. We hypothesized that at 1 yr post-fire 1) establishment of post-fire seeded perennial bunchgrasses would be greater in subcanopy microsites compared to interspace microsites as evidenced by higher seedling density, and 2) the performance of post-fire seeded perennial bunchgrasses would be greater in subcanopy compared to interspace microsites as evidenced by greater seedling height and a higher percentage of microsites with seedlings in a reproductive state (i.e., with developed seed heads).

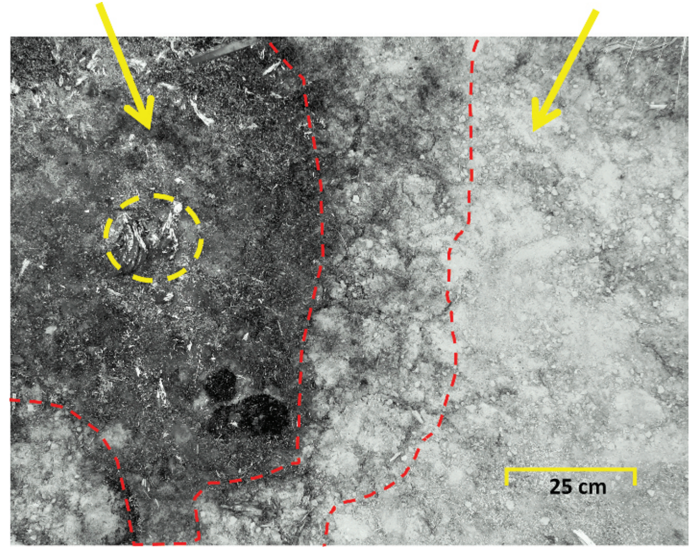

Figure 1. Following fire, areas within the sagebrush subcanopy appeared as blackened (left arrow) as compared to interspace areas (right arrow). Contiguous black areas (enveloped by dotted red line on left) were used to define subcanopy microsites, and contiguous nonblackened areas (separated by dotted red line on right) were defined as interspace. Residual stump of original sagebrush is within dotted circle at left.

METHODS AND MATERIALS

Study Sites

This study was conducted in the Wyoming big sagebrush alliance approximately 65 km east of Burns, Oregon (lat 43.48°N, long 119.72°W). Elevation at study sites was approximately 1 100 m, and slopes were 2–5%. Aspect varied between sites in an approximately 180° range, and sites were located within two Bureau of Land Management (BLM) grazing allotments with differing management histories. Soils were a complex series, and surface textures ranged from clayey to silty or gravelly loam underlain by clay pan or bedrock at depths from 10 cm to 50 cm (Natural Resources Conservation Service 2007). Our study occurred within multiple rangeland ecological sites: SR Adobeland 9-12PZ, SR Clayey 9-12PZ, and SR Shallow 9-12PZ (Natural Resources Conservation Service 2007). Annual precipitation is highly variable but averages approximately 284 mm, with the majority falling as rain or snow during the October to March period; precipitation impacting germination, emergence, growth, and survival of seedlings in this study (1 October 2007 to 30 June 2008) was 90% of the long-term average (Drewsey, Oregon, weather station; Oregon Climate Service 2007).

A 13 000-ha area, which included our study sites, was burned by wildfire in July 2007. The area in the vicinity of our study sites was burned completely, indicating sufficiency of fine fuel loading. Direct measurements of fire behavior/intensity are not available; however, weather on the day the fire started was extreme: maximum air temperature of 38.9°C, low of 7% relative humidity, and wind gusts to 54.4 $km \cdot h^{-1}$ (Burns District BLM file data). Prior to burning, this area was sagebrush/bunchgrass vegetation characterized by Wyoming big sagebrush, bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love), Great Basin wildrye (*Leymus cinereus* [Scribn. & Merr.] A. Love), Sandberg bluegrass (*Poa secunda* J. Presl), and medusahead (*Taeniatherum caput-medusae* [L.] Nevski). Our study sites were within a 4 000-ha area of the burn that was seeded with a drill in October 2007. The seed mix included 4.5 $kg \cdot ha^{-1}$ of crested wheatgrass (*Agropyron cristatum* L.), 2.2 $kg \cdot ha^{-1}$ of Siberian wheatgrass (*Agropyron sibiricum* [Wild.] Beauv.), 2.25 $kg \cdot ha^{-1}$ of bluebunch wheatgrass, 1.12 $kg \cdot ha^{-1}$ of Secar bluebunch wheatgrass (*Elymus wawawaiensis* J. Carlson & Barkworth), 0.56 $kg \cdot ha^{-1}$ of Great Basin wildrye, and 0.56 $kg \cdot ha^{-1}$ of Sandberg bluegrass. Prior to burning the study area was grazed by cattle during the growing season. Grazing was curtailed following fire in 2007 with continued nonuse in 2008.

Experimental Design and Measurements

We used a randomized block design with five blocks (sites) and two treatment levels (interspace or subcanopy). In October 2008, we identified five burned sites that had supported sagebrush at the time of burning (based on previous research in the area; Davies and Svejcar 2008). Extreme distance between sites was approximately 2 km. Sagebrush subcanopy microsites were associated with persistent dead woody material and were characterized by a blackened soil surface (Fig. 1); "persistent" indicated a sagebrush base with below-ground plant parts still anchoring it in place. These shrub-associated microsites ranged in size from 50 cm to 100 cm in diameter. At each study site we randomly selected 20 subcanopy and 20 interspace microsites (the latter were characterized by a soil surface that was not visibly blackened and did not contain persistent dead woody material or live shrubs; Fig. 1). After randomly selecting a subcanopy microsite, we selected the paired interspace microsite by walking on a random azimuth until we encountered interspace large enough to contain a 40×50 cm quadrat. For purposes of data collection and analysis we grouped seeded species and labeled *Agropyron* as "non-native" and the remaining genera as "native." At each microsite, we counted the number of perennial grass seedlings, by species group (native or non-native), within a 40×50 cm quadrat and measured the average seedling height by species group during October 2008. Only those seedlings occurring within a drill row were counted. Seedlings alive in October 2008 were considered "established" because survival through the first growing season represents a major life history milestone for perennial bunchgrasses. For analysis purposes we expressed seedling density both as the number of seedlings per unit area, and, because native and non-native seeds were planted at different rates, as the number of seedlings within a 0.2-m^2 quadrat/number of seeds planted in that quadrat (i.e., "percentage density"). Presence or absence of reproductive seedlings (visible seed head) was noted by species group for each quadrat.

Statistical Analysis

Data were analyzed using Statistical Analysis Software (SAS Institute 1999) and the PROC MIXED module. Independent variables in the model included microsite, species group, and microsite * species group; site and site * treatment were random factors. Response variables were seedling density (by area and as a percentage of seeds planted), height, and reproductive status. We used inverse variance weighting (Neter et al. 1990; James and Drenovsky 2007) based on treatment and species due to heterogeneity of variance between treatments. Means are presented with their associated standard errors.

RESULTS

Non-natives dominated the perennial grass seedling population ($P < 0.001$) based on density (by area) with 1.91 seedlings $\cdot$ 0.2 m^{-2} ($\pm$ 0.49) compared to 0.25 seedlings $\cdot$ 0.2 m^{-2} ($\pm$ 0.14) for natives. Native seedlings were not present at one site for subcanopy microsites and three sites for interspace microsites; non-natives were present for all site/microsite combinations. The effect of microsite on percentage density varied by species group ($P < 0.001$). Percentage density of non-native seedlings in subcanopy microsites ($\bar{x} = 6.3\% \pm 0.65$) was about six times higher ($P < 0.001$) than interspace microsites ($\bar{x} = 0.98\% \pm 0.20$; Fig. 2). For native seedlings, percentage density at subcanopy microsites ($\bar{x} = 1.15\% \pm 0.60$) was 24 times higher ($P = 0.016$) than interspace microsites (0.05% $\pm$ 0.03; Fig. 2). In contrast to density, native and non-native seedlings had similar performance with respect to height ($P = 0.995$), but seedling height varied by microsite ($P < 0.001$). Seedling height for subcanopy microsites (across species) averaged 25.63 cm ($\pm$ 1.95) compared to 11.48 cm ($\pm$ 1.02) for interspace microsites (Fig. 2). Microsite effects on presence of reproductive seedlings varied by species group ($P < 0.001$). In subcanopy microsites, a higher percentage of plots ($P < 0.001$) contained non-native reproductive seedlings (28% $\pm$ 4.9) compared to natives (3.0% $\pm$ 2.0; Fig. 2). The percentage of subcanopy microsite plots containing native reproductive seedlings did not differ from the percentage of interspace microsite plots containing native ($P = 0.447$) or non-native ($P = 0.447$) reproductive

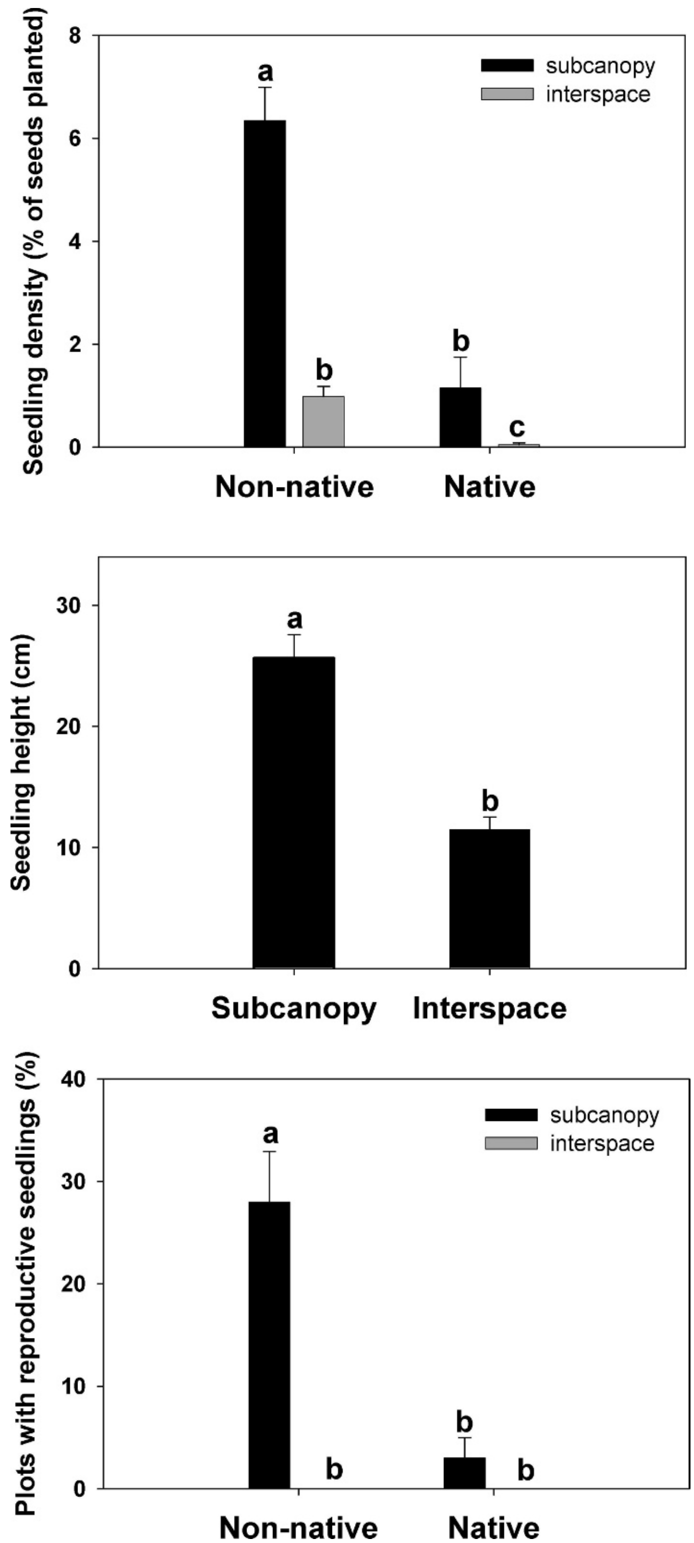

Figure 2. Seedling density, height, and percentage of plots with reproductive seedlings in burned Wyoming big sagebrush plant communities. Seedling density was calculated as the number of seedlings within a 0.2-m^2 quadrat per the number of seeds planted. Means are presented with their associated standard errors. Data were collected in October 2008, approximately 1 yr post-seeding, and 15 mo after the wildfire. Within a graph, bars without a common letter are different ($\alpha = 0.05$).

seedlings (Fig. 2). No reproductive seedlings were found within interspace microsites.

DISCUSSION

Subcanopies were more conducive microsites for establishment and performance of perennial grasses seeded after wildfire. The 6- and 24-fold difference in density of introduced and native perennial bunchgrass, respectively, between burned subcanopies and burned interspaces, along with increases in height and reproductive effort of subcanopy seedlings, suggests that shrubs have significant influence on the spatial success of revegetation efforts. These results also support speculation by Davies et al. (2009) that subcanopy and interspace microsites could have significant implications for post-fire community assembly and diversity.

Our results are consistent with the idea that spatial heterogeneity of environmental and soil characteristics created by shrubs produces spatial heterogeneity in seedling success. Recent research suggests that shrub-associated alterations in soil properties may have at least short-term persistence after burning of the shrub, although distinctions between subcanopy and interspace microsites may be reduced (Davies et al. 2009). There is also a large increase in soil inorganic nitrogen the first year post-fire for subcanopy microsites (Stubbs and Pyke 2005; Davies et al. 2009). Eckert et al. (1986) reported reduced soil physical crusts in subcanopy microsites; soil physical crusts can reduce the establishment success of vegetation (Escudero et al. 2000; Maestre et al. 2003). Another factor that could impact seedling success in subcanopy microsites is the darkening of the soil surface with fire (Fig. 1). Soil temperatures have been reported to increase on blackened soil surfaces following burning, leading to earlier growth initiation in spring and effectively lengthening the growing season (Covington and Sackett 1984; Wrobleski and Kauffman 2003; Davies et al. 2009). An earlier, extended growing season may be especially critical in regions where most of the precipitation occurs during winter.

Our data also indicate that at the seeding rates used in this study non-native perennial bunchgrasses were more likely to establish than native perennial bunchgrasses. Others authors have reported similar results (Robertson et al. 1966; Hull 1974). Some research has suggested that increased competitive fitness of crested wheatgrass may negatively influence establishment of native seedlings (Caldwell et al. 1985; Eissenstat and Caldwell 1987). Thus, competition between non-native and native perennial bunchgrasses may have contributed to the limited establishment of native perennial bunchgrasses in our study. Increased success and lower cost have bolstered use of non-native perennial grasses compared to native perennial grasses in post-fire rehabilitation of Wyoming big sagebrush communities (Eiswerth et al. 2009), particularly where the threat from annual grass invasion is high.

IMPLICATIONS

Under the fire conditions examined in this study, shrub microsites exerted a post-fire influence on the heterogeneity of revegetation success as demonstrated by greater establishment and performance of post-fire seeded perennial grasses in subcanopy microsites. Seeded non-native perennial grasses were more successful (based on density and reproduction) than seeded native perennial grasses. The fact that subcanopy seedling density, height, and reproductive effort increased simultaneously suggests that shrubs were promoting local resource availability post-fire, consistent with the resource islands often reported in non-burned arid and semi-arid shrub systems. Additional research to determine the mechanism(s) facilitating greater establishment in burned subcanopy microsites may provide information that could be incorporated into existing restoration technologies to improve efforts to revegetate Wyoming big sagebrush communities after fire.

ACKNOWLEDGMENTS

We thank two anonymous reviewers who provided valuable comments on an earlier draft of this manuscript. We also thank Jeff Rose with Burns District (Oregon) Bureau of Land Management (BLM) for stimulating our interest in the potential importance of shrub microsites to seeded perennial grass establishment. Lastly we thank the Burns District BLM for allowing us to conduct this research on land within their management purview.

LITERATURE CITED

Beyers, J. L. 2004. Postfire seeding for erosion control: effectiveness and impacts on native plant communities. *Conservation Biology* 18:947–956.

Caldwell, M. M., D. M. Eissenstat, J. H. Richards, and M. F. Allen. 1985. Competition for phosphorus: differential uptake from dual-isotope-labeled soil interspaces between shrub and grass. *Science* 229:384–386.

Charley, J. L., and N. E. West. 1977. Micro-patterns of nitrogen mineralization activity in soils of some shrub-dominated semi-desert ecosystems of Utah. *Soil Biology Biochemistry* 9:357–365.

Covington, W. W., and S. S. Sackett. 1984. The effect of a prescribed burn in southwestern ponderosa pine on organic matter and nutrients in woody debris and forest floor. *Forest Science* 30:183–192.

Davies, K. W. 2008. Medusahead dispersal and establishment in sagebrush steppe plant communities. *Rangeland Ecology & Management* 61:110–115.

Davies, K. W., J. D. Bates, and J. J. James. 2009. Microsite and herbaceous vegetation heterogeneity after burning *Artemisia tridentata* steppe. *Oecologia* 159:98–110.

Davies, K. W., J. D. Bates, and R. F. Miller. 2007. The influence of *Artemisia tridentata* spp. *wyomingensis* on microsite and herbaceous vegetation heterogeneity. *Journal of Arid Environments* 69:441–457.

Davies, K. W., and T. J. Svejcar. 2008. Comparison of medusahead-invaded and noninvaded Wyoming big sagebrush steppe in southeastern Oregon. *Rangeland Ecology & Management* 61:623–629.

Doescher, P. S., R. F. Miller, and A. H. Winward. 1984. Soil chemical patterns under eastern Oregon plant communities dominated by big sagebrush. *Soil Science Society of America Journal* 48:659–663.

Eckert, R. E., F. F. Peterson, M. S. Meurisse, and J. L. Stephens. 1986. Effects of soil-surface morphology on emergence and survival of seedlings in big sagebrush communities. *Journal of Range Management* 39:414–420.

Eissenstat, D. M., and M. M. Caldwell. 1987. Characteristics of successful competitors: an evaluation of potential growth rate in two cold desert tussock grasses. *Oecologia* 71:167–173.

Eiswerth, M. E., K. Krauter, S. R. Swanson, and M. Zielinski. 2009. Post-fire seeding on Wyoming big sagebrush ecological sites: regression analysis of seeded nonnative and native species densities. *Journal of Environmental Management* 90:1320–1325.

Escudero, A., J. M. Irondo, J. M. Olando, A. Rubio, and R. C. Somolinos. 2000. Factors affecting establishment of a gypsophyte: the case of *Lepidium subulatum* (Brassicaceae). *American Journal of Botany* 87:861–871.

Hull, A. C., Jr. 1974. Species for seeding arid rangeland in southern Idaho. *Journal of Range Management* 27:216–218.

Hunter, M. E., P. N. Omi, E. J. Martinson, and G. W. Chong. 2006. Establishment of non-native species after wildfires: effects of fuel treatments, abiotic and biotic factors, and post-fire grass seeding treatments. *International Journal of Wildland Fire* 15:271–281.

Jackson, R. B., and M. M. Caldwell. 1993a. Geostatistical patterns of soil heterogeneity around individual perennial plants. *Journal of Ecology* 81:683–692.

Jackson, R. B., and M. M. Caldwell. 1993b. The scale of nutrient heterogeneity around individual plants and its quantification with geostatistics. *Ecology* 74:612–614.

James, J. J., K. W. Davies, R. L. Sheley, and Z. T. Aanderud. 2008. Linking nitrogen partitioning and species abundance to invasion resistance in the Great Basin. *Oecologia* 156:637–648.

James, J. J., and R. E. Drenovsky. 2007. A basis for relative growth rate differences between native and invasive forb seedlings. *Rangeland Ecology and Management* 60:395–400.

Keeley, J. E. 2004. Ecological impacts of wheat seeding after a Sierra Nevada wildfire. *International Journal of Wildland Fire* 13:73–78.

Maestre, F. T., A. J. Cortina, S. Bautista, J. Bellot, and R. Vallejo. 2003. Small-scale environmental heterogeneity and spatiotemporal dynamics of seedling establishment in a semiarid degraded ecosystem. *Ecosystems* 6:630–643.

Mensing, S., S. Livingston, and P. Barker. 2006. Long-term fire history in Great Basin sagebrush reconstructed from macroscopic charcoal in spring sediments, Newark Valley, Nevada. *Western North American Naturalist* 66:64–77.

Natural Resources Conservation Service. 2007. Soil Survey of Harney County Area, Oregon. Available at: http://soildatamart.nrcs.usda.gov/Manuscripts/OR628/0/Harney.pdf. Accessed 8 October 2008.

Neter, J., W. Wasserman, and M. H. Kutner. 1990. Applied linear statistical models: regression, analysis of variance and experimental design. 3rd ed. Homewood, IL, USA: Irwin. 1408 p.

O'Connor, T. G. 1996. Hierarchical control over seedling recruitment of bunchgrass *Themeda triandra* in a semi-arid savanna. *Journal of Applied Ecology* 33:1094–1106.

Oregon Climate Service. 2007. Oregon Climate Summary. Available at: http://www.ocs.oregonstate.edu/index.html. Accessed 8 October 2008.

Rafferty, D. L., and J. A. Young. 2002. Cheatgrass competition and establishment of desert needlegrass seedlings. *Journal of Range Management* 55:70–72.

Robertson, J. H., R. E. Eckert, and A. T. Bleak. 1966. Response of grasses seeded in an *Artemisia tridentata* habitat in Nevada. *Ecology* 47:187–194.

SAS Institute. 1999. SAS procedures guide, release 8.0. Cary, NC, USA: SAS Institute. 554 p.

Schlesinger, W. H., J. A. Raikes, A. E. Hartley, and A. F. Cross. 1996. On the spatial patterns of soil nutrients in desert ecosystems. *Ecology* 77:364–374.

Stewart, G., and A. C. Hull. 1949. Cheatgrass (*Bromus tectorum* L.): an ecologic intruder in southern Idaho. *Ecology* 30:58–74.

Stubbs, M. M., and D. A. Pyke. 2005. Available nitrogen: a time-based study of manipulated resource islands. *Plant and Soil* 270:123–133.

Wright, H. A., and A. W. Bailey. 1982. Fire ecology: United States and southern Canada. New York, NY, USA: John Wiley. 501 p.

Wrobleski, D. W., and J. B. Kauffman. 2003. Initial effects of prescribed fire on morphology, abundance, and phenology of forbs in big sagebrush communities in southeastern Oregon. *Restoration Ecology* 11:82–90.

Young, J. A., and F. L. Allen. 1997. Cheatgrass and range science: 1930–1950. *Journal of Range Management* 50:530–535.